Results of 3-D Seismic Carbonate Project, West Texas
Part 1: Overview, Reservoir Characteristics, and Geophysics; Part 2: Borehole Electrical Images from Microresistivity Logs of the Fractured, Karsted, and Brecciated Ellenburger Group

Part 1

Bruce A. Cain (bacain@shellus.com, 281/544-2765)
Shell Western E&P Inc.
P.O. Box 576
Houston, TX 77001

ABSTRACT

A large cooperative field study began in January 1996 and is focused on Lower Paleozoic gas reservoirs in the Permian Basin, West Texas (Figure 1). The purpose is to evaluate development options for prolific, mature, carbonate gas reservoirs in a structurally-complex geologic province. New economic gas reserves likely exist in untapped fault blocks or poorly drained reservoir compartments within the Delaware and Val Verde Basins. Geologic structure and reservoir development is being evaluated utilizing 3-D seismic techniques and a multidisciplinary team approach. The cooperative research is supported by U.S. Department of Energy, GRI, Texas Bureau of Economic Geology, Shell Western E&P Inc., Mobil E&P U.S. Inc., Landmark Graphics, Schlumberger, Petroleum Information Inc., and Tobin Data Graphics.

RESEARCH OBJECTIVES

The Lockridge-Waha 3-D study (Figure 2) will focus on:

A) 3-D feasibility in a highly structured setting with difficult near-surface conditions,
B) field-scale reservoir model(s) for karst, fractured carbonate horizons, and
C) economic assessment of “3-D Seismic/Integrated Team” development strategy.

Phase I of the project involves the design, acquisition, and processing of a 3-D seismic survey. Key technical issues are seismic data quality and cost optimization. Phase II involves a detailed field study based on proprietary subsurface data. This integrated study will combine geology, geophysics, and reservoir engineering concepts. Phase III is technology transfer of tools and concepts. Tech transfer agents have been involved since project start-up.

MAJOR ACCOMPLISHMENTS TO DATE

Major progress has been made to improve seismic data quality through new 3-D design software and seismic modeling of the shallow Tertiary Fill. The 3-D design software optimizes seismic parameters of high fold, wide azimuth, and long offsets while identifying the most cost effective pattern of shot points and geophone receivers. Commercial software development has been awarded to Green Mountain Geophysical in cooperation with Shell and ARCO. Seismic improvement has also been achieved for problems related to the shallow Tertiary Fill. A three-layer refraction model (Figure 3) has been created and matched to the shallow geology, resulting in a more accurate time correction factor for Tertiary Fill effects. The process has been automated using a neural net picker, reducing geophysical staff time by 60 percent. Major progress has also been made for reservoir characterization through an integrated core and borehole image study from analog Ellenburger gas fields (see Part 2).

Carbonate Reservoir Overview

Delaware Basin gas fields are faulted, anticlinal traps that formed during mid-Pennsylvanian to early Permian time. The basin experienced pulses of intense compression as well as shear resulting in complicated, compact, variable-relief structures ranging from several hundred to several thousand feet of closure. Inherent in this structural style are short, complex faults with abruptly changing throws and hinge points. Current 2-D seismic invariably aliases fault patterns and is insufficient to accurately define fault blocks. Seismic imaging of such complex geometries requires 3-D technology.

Dominant reservoir fabrics are karst breccia and fractures related to ancient cave systems which result in highly variable productivity in both a stratigraphic and areal sense. High permeability but modest porosity fabrics can range from chaotic breccia associated with cave collapse or highly fractured dolomite related to cave compaction. Paleostructure studies are essential in understanding the relationships of structural growth to karst reservoir development. Pay intervals range from 50 to 800 feet at depths of 11,000 to 22,000 feet. Pressure depletion and water drives are the primary production mechanisms. Gas fields, on average, have produced 80 to 90% of proven reserves and have had little or no recent drilling. We believe by combining our significant experience in Permian Basin carbonates and 3-D technology that substantial advancements are possible.

Carbonate reservoir models for the Lower Paleozoic must explain low-decline production histories, sporadic permeability development, short distance pressure variations, and complex compartments. The focus of the research program is to develop a usable model that accurately describes the reservoir dynamics and structural related compartments on a field scale. The integration of production characteristics, accurate structural maps, and paleostructural history are considered essentials. Regional reservoir concepts and business models need to be developed, refined, and tested for the Delaware Basin gas trend.

Part 2: Borehole Electrical Images from Microresistivity Logs of the Fractured, Karsted, and Brecciated Ellenburger Group

Ursula Hammes (hammesu@begv.beg.utexas.edu; 512-475-9573)
Bureau of Economic Geology, The University of Texas at Austin
University Station, Box X
Austin, TX 78713

ABSTRACT

Electrical images in boreholes are becoming increasingly important in interpreting the rock record. In addition to identifying fractures and faults, borehole imaging tools are used for a variety of other applications such as horizontal drilling, environmental studies, stress orientation measurement studies, sequence stratigraphy, paleotransport, facies, and diagenetic analyses. These tools produce electrical microconductivity images of the wellbore, which are interpreted using an interactive graphics workstation. High-resolution (~ 2.5-mm) and nearly complete borehole coverage can greatly increase the detail and precision of geological interpretations. Yet, to be fully useful, borehole images should be calibrated with core. This study provides the first comprehensive comparison of carbonate features in cores with a suite of all currently available electrical imaging logs. The Lower Ordovician Ellenburger Group, West Texas, serves as a model for a dolomitized, fractured, karsted, and brecciated carbonate reservoir. Characteristic reservoir features, including fracture breccia, chaotic breccia, laminated mudstones, grainstones, and bioturbation are identified both on electrical imaging logs and in cores. Electrical images provide more complete information than cores in cavernous and highly fractured zones because cores commonly show no recovery or occur as rubble in these zones, which are the most productive zones in the Ellenburger reservoir. Borehole imaging, therefore, provides in-situ visualization of cavernous porosity, chaotic breccias or conglomerates, and highly fractured intervals, as well as other key insights into karst stratigraphy.

INTRODUCTION

This study, also published through the Bureau of Economic Geology, The University of Texas at Austin (Geological Circular 97-2), is the first comprehensive collection of Schlumberger's Formation Microscanner™/Formation MicroImager™ (FMS/FMI) and Halliburton's Electrical MicroImager™ (EMI) images and their comparison to cores of fractured, brecciated, and karsted carbonate reservoirs. When images are calibrated with cores their three-dimensional display benefits reservoir evaluation by extending core data to other wells. Typical electrical images of facies, karst and breccia fabrics, and structural and diagenetic features were calibrated to selected cores from the Lower Ordovician Ellenburger Group, West Texas. The Ellenburger Group was selected for study because many carbonate reservoirs throughout the Ellenburger rock record are extensively fractured, brecciated, karsted, and dolomitized. Cavernous or highly fractured intervals are the most productive zones in the Ellenburger reservoirs, but these intervals are commonly not detected in cores because of poor recovery within these zones. Electrical images are thus valuable tools in identifying the karst stratigraphy, location of cavernous porosity, chaotic breccias, and highly fractured intervals. Detailed and whole-core pictures from 18 cores of the Ellenburger Group were photographed and compared to 23 different FMI, FMS, and EMI images. Similar features were viewed and enhanced on a Sun workstation and displayed next to the digitized core photos. This study presents the correlation of numerous core and electrical imaging examples of the Ellenburger Group in West Texas.

RESULTS

The electrical images are derived from 3-D, high-resolution, micro-resistivity tools that cover approximately 60 to 80% of an 8-inch (20-cm) borehole wall. These images are increasingly incorporated in a general logging suite because they enhance core interpretations, improve the placement of perforations, and enhance reservoir geometries and diagenetic, structural, and stratigraphic features across fields. The images focus on depositional and post-depositional fabrics of the Ellenburger Group compared to the core photographs and are divided into two parts, one showing depositional facies, the second displaying mostly diagenetic features. The Ellenburger Group is an up to 1500-ft-thick sequence of laminated mudstones, bioturbated mud/wackestones, and peloidal/ooid grainstones (Figure 4) that was deposited on a shallow-water, restricted carbonate platform (Kerans, 1990). Approximately 30 m.y. exposure during the post-Sauk unconformity led to the development of a vast karst platform and formation of an extensive, multiphase cave system (Hammes et al., 1996). Upon burial, most of the cave system collapsed, forming a characteristic tripartite sequences of breccias (Kerans, 1990). These breccias are identified as fracture and mosaic breccias (Figure 5), which are interpreted as the cave roof, chaotic breccias (Figure 6), which are interpreted as the cave floor, and cave fill. Several successive tectonic events caused fractures and faults that evolved into these heterogeneous carbonate reservoirs. Borehole imaging provides insight into the karst stratigraphy, location of cavernous porosity, chaotic breccias or conglomerates, and highly fractured intervals.

SUMMARY

When images are calibrated with cores their three-dimensional display benefits reservoir evaluation by extending core data to other wells. This paper exhibits three examples of electrical images from a comprehensive collection of carbonate features seen in electrical microresistivity images compared to carbonate cores of the Ellenburger Group. The images and cores show depositional and diagenetic carbonate features characteristic of the Ellenburger Group, which is a fractured, karsted, and brecciated carbonate reservoir and serves as an example for similar carbonate reservoirs. A suite of FMS/FMI and EMI images provided insight into karst stratigraphy, facies types, location of cavernous porosity, extensively fractured intervals, and karst breccias. These features, in addition to facies and diagenetic features, were calibrated with cores. The result is a comprehensive catalog that compares actual rocks to microresistivity images.

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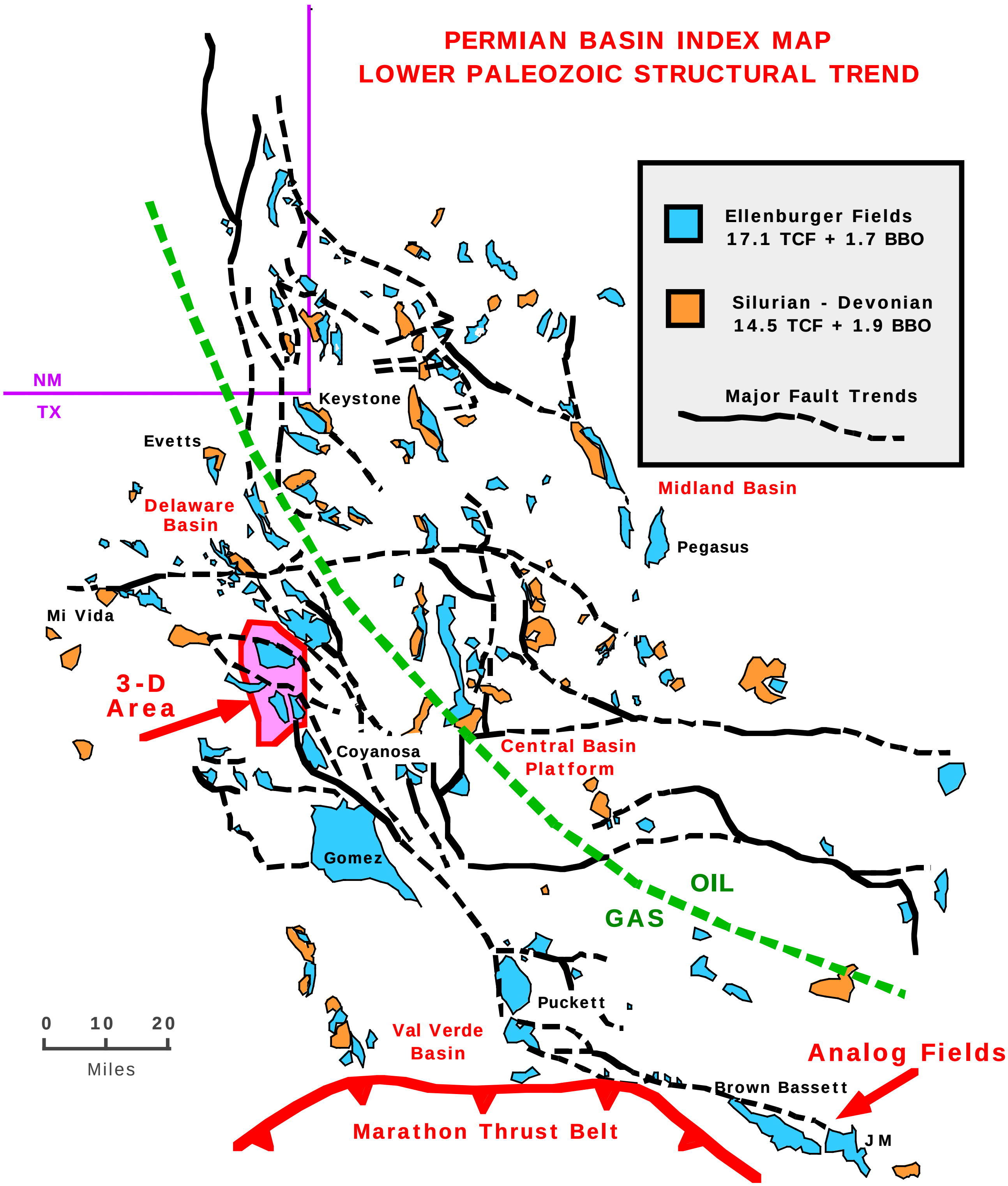

Figure 1. Permian Basin index map showing 3-D study area and analog fields. (Map from Shumaker, 1992.)

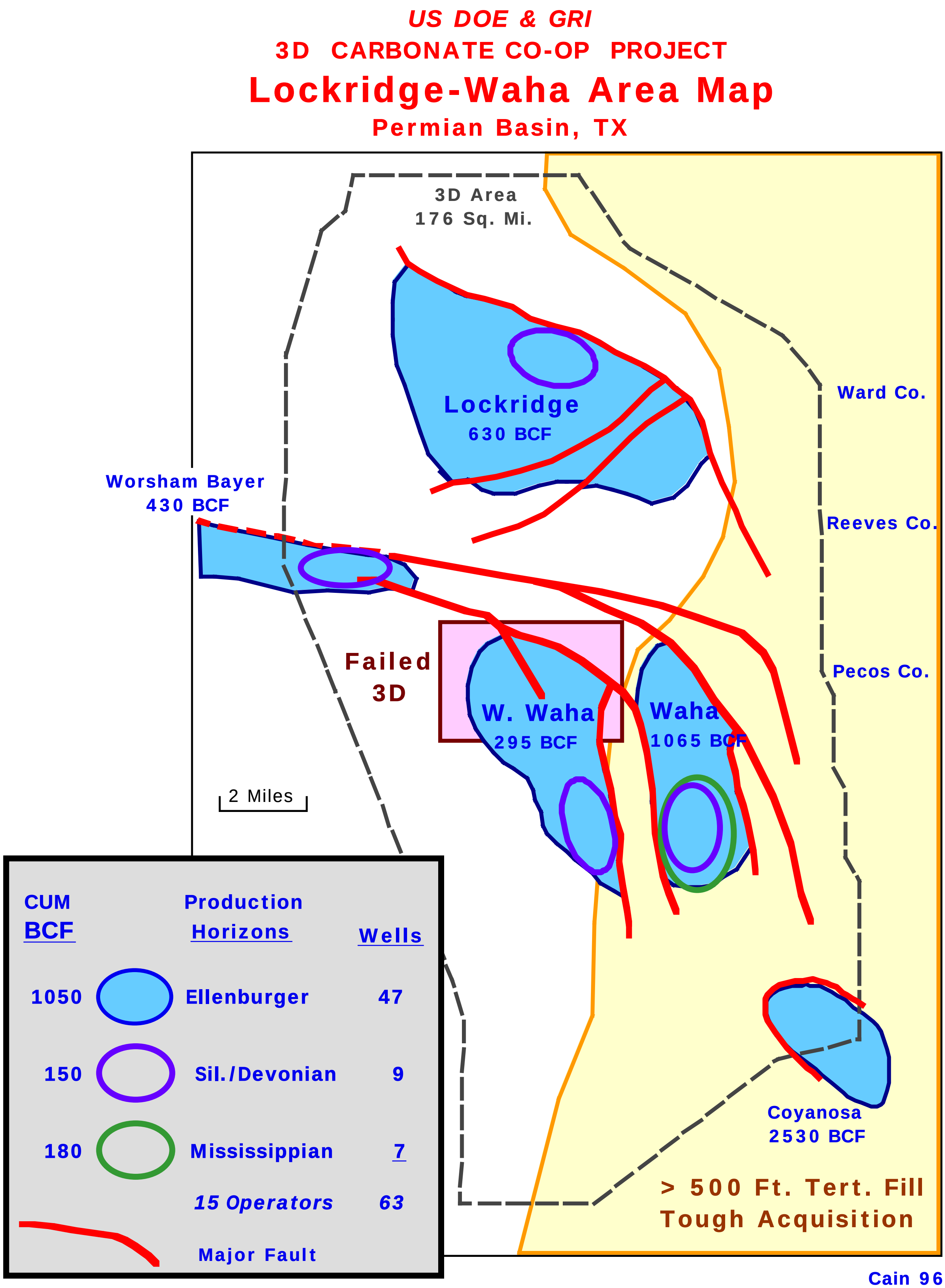

Figure 2. Lockridge-Waha 3-D study area (Ward, Pecos, and Reeves Counties, TX). Thick Tertiary Clastics (yellow) occur on the east half of 3D survey and are the most difficult acquisition area.

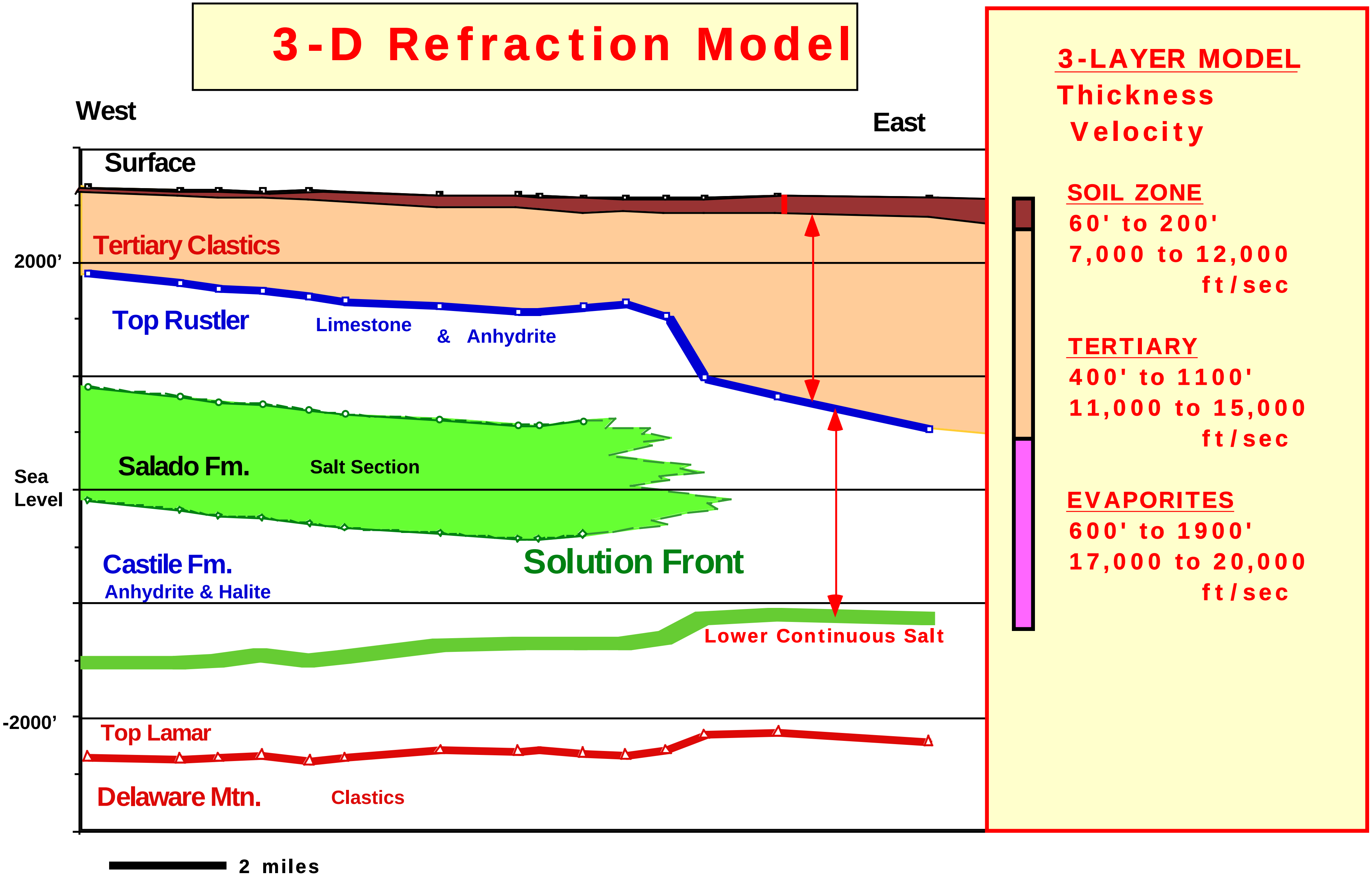

Figure 3 East-West geologic cross section depicting Tertiary clastics and Permian evaporites. The solution front and rapid increase in clastic thickness cause severe statics problems.

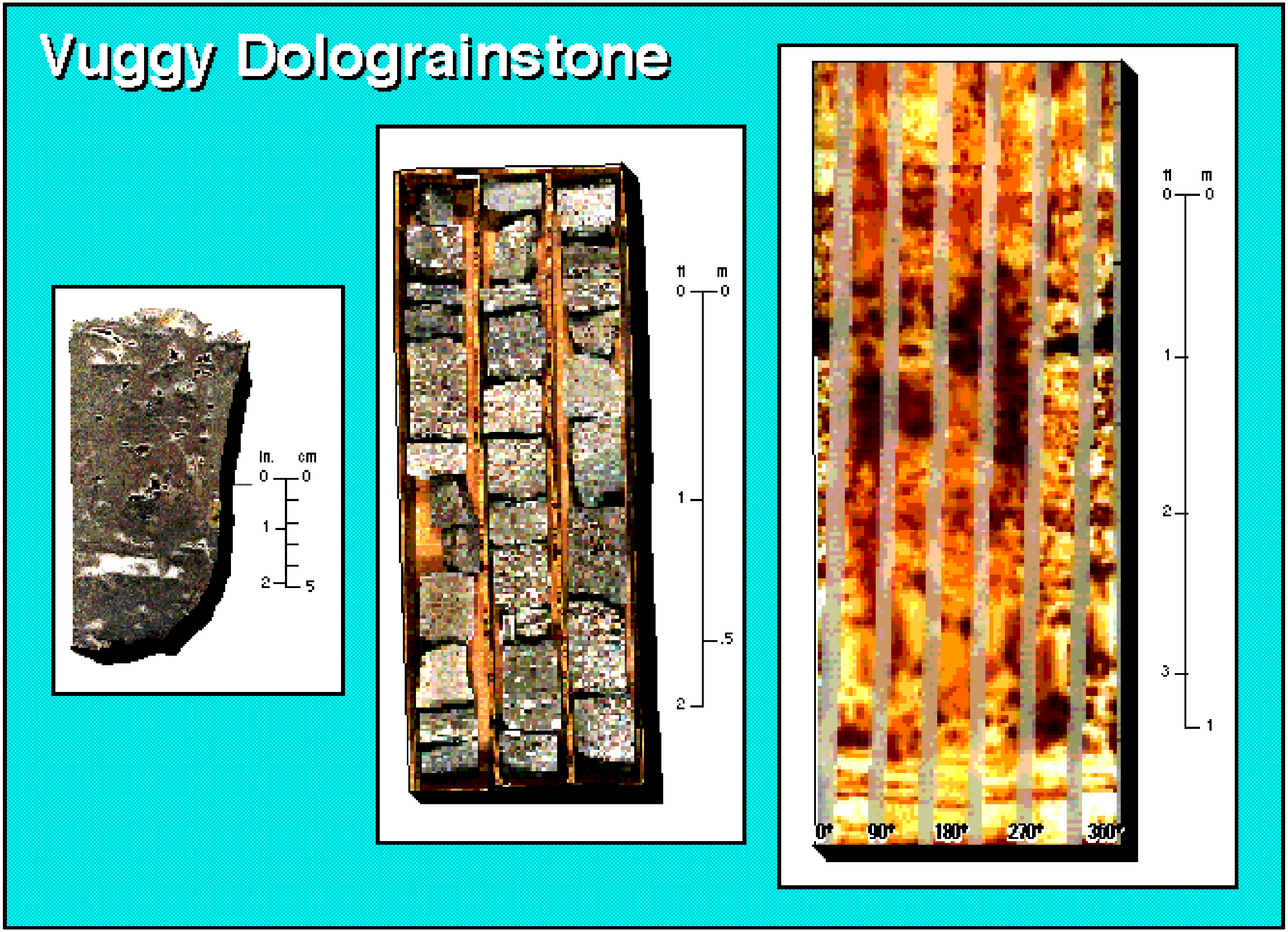

Figure 4: EMI image and core photographs of a dolograinstone with abundant vuggy porosity (Ellenburger Group, Eastern Shelf). Grainstones are tightly cemented and appear highly resistive. Vuggy pores are indicated by dark, conductive rounded to elliptical features. This facies is characteristic for the shoal environment.

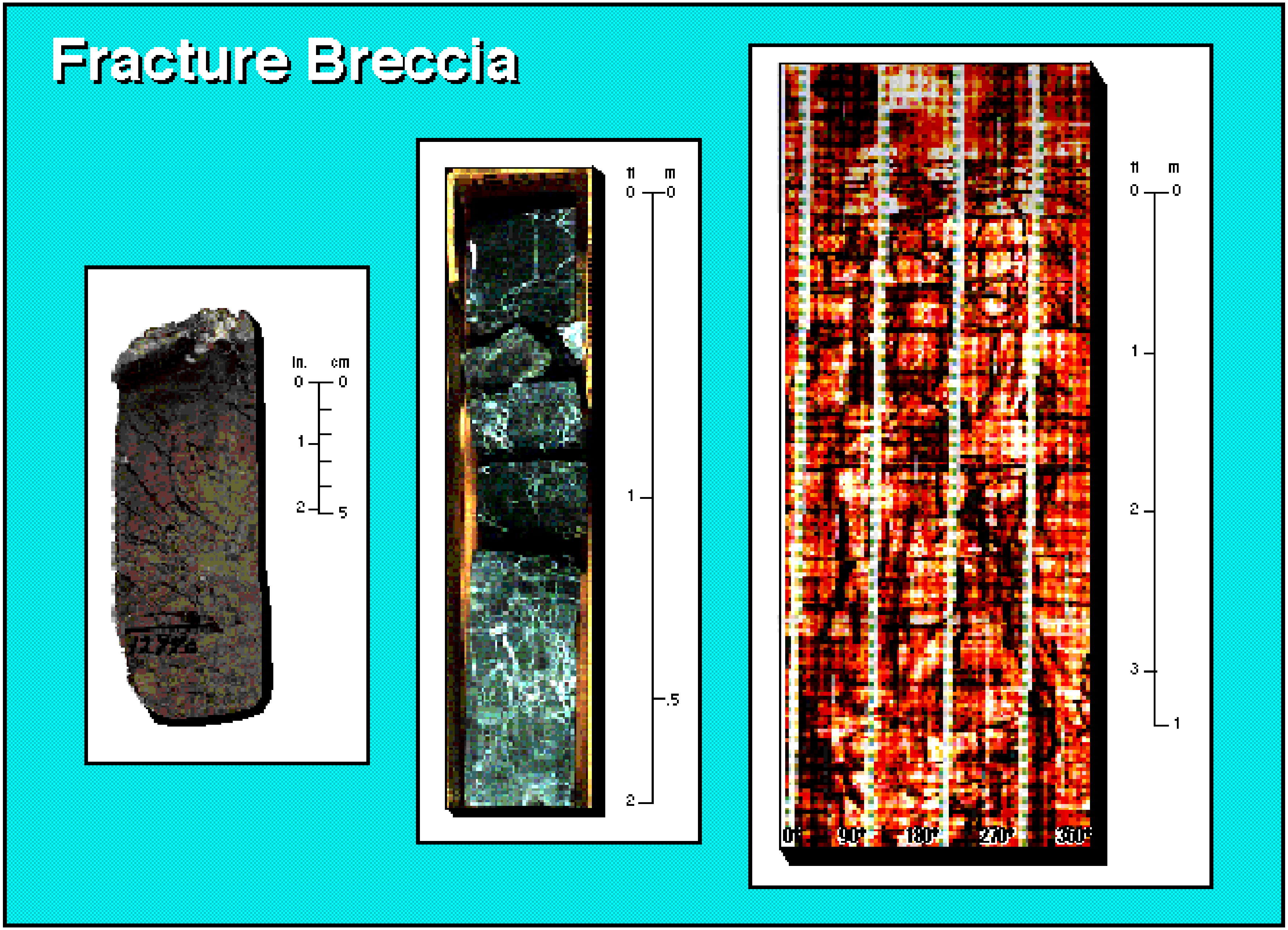

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Figure 5: FMI image and core photos of a fracture breccia (Ellenburger Group, Eastern Shelf). Fractures appear as black, highly conductive, mainly vertical features in a laminated mudstone. Note that many fractures terminate at bedding and laminae planes.

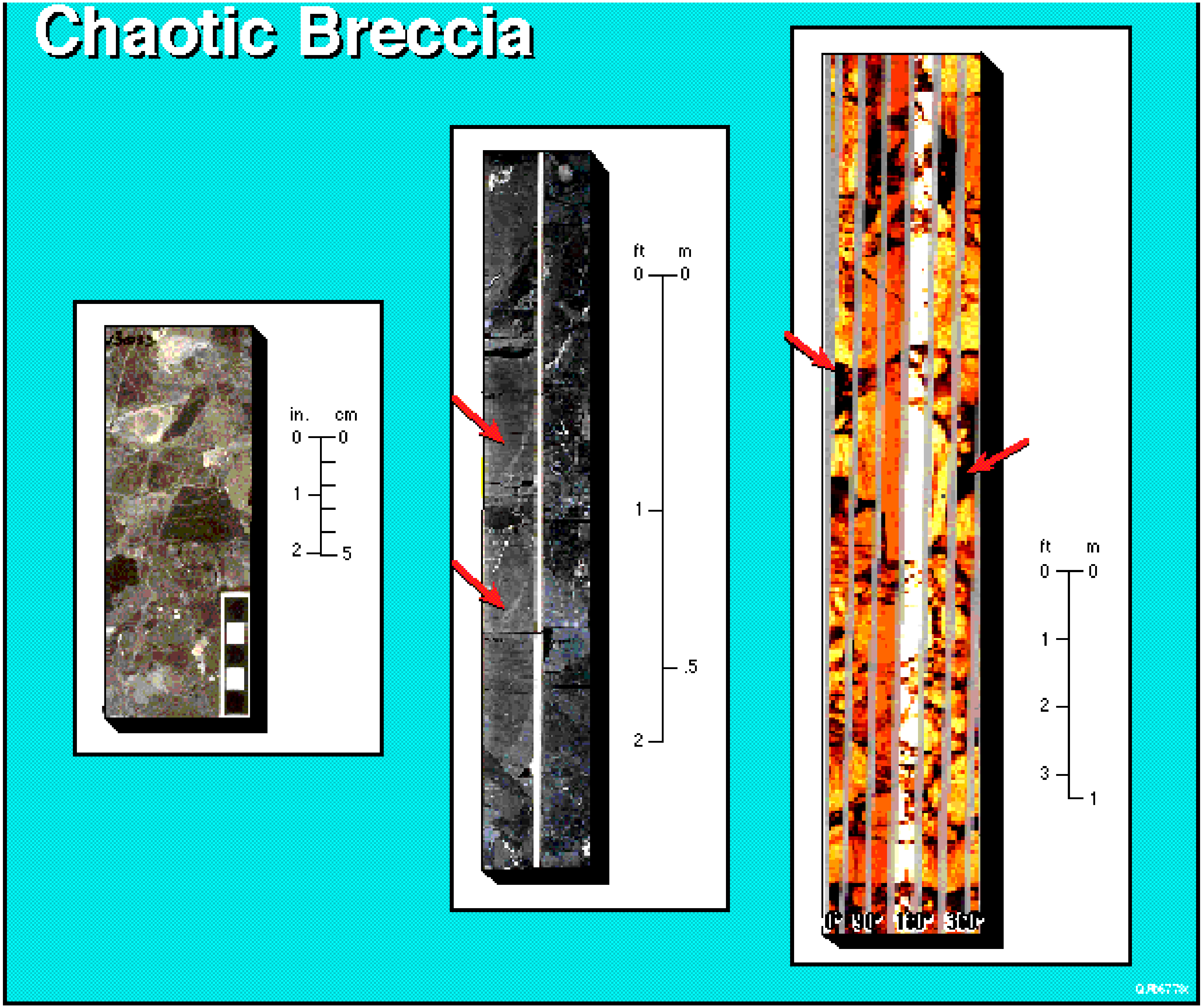

Figure 6: EMI image and core photos of a carbonate-matrix supported chaotic breccia (Ellenburger Group, Eastern Shelf). Clasts are typically highly resistive and range in size from millimeter to meters. The matrix between clasts is moderately to highly conductive. The dark conductive features next to the large clast (arrows) are interpreted as cavernous porosity. Meter-sized clasts